

A Search for pair production of the LSP $\tilde{\nu}_\tau$ at the CLIC via RPV Decays

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Abstract

In this work we consider pair production of LSP tau-sneutrinos at the Compact Linear Collider. We assume that tau-sneutrinos decays in to $e\mu$ pair via RPV interactions. Backgroundless subprocess $e^-e^+ \rightarrow \tilde{\nu}\tilde{\nu} \rightarrow \mu^+\mu^+e^-e^-(\mu^-\mu^-e^+e^+)$ is analyzed in details. Achievable limits on $Br(\tilde{\nu}_\tau \rightarrow \mu e)$ at 3σ and 5σ CL are obtained depending on $\tilde{\nu}_\tau$ mass.

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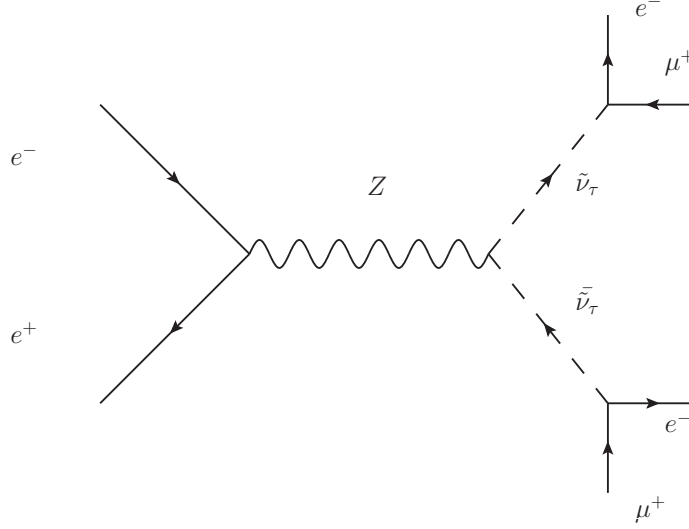


Figure 1: Feynman diagram for $e^+e^- \rightarrow \tilde{\nu}_\tau \bar{\tilde{\nu}}_\tau \rightarrow \mu^+e^- \mu^+e^-$ process.

Supersymmetry (SUSY) is one of the favorite candidates for the Beyond the Standard Model (BSM) physics [1]. For this reason, searching for supersymmetric particles forms an essential part of the LHC, as well as future colliders, experimental programmes. Searching strategy for SUSY strongly depends on the lightest supersymmetric particle (LSP), as well as R-parity conservation or violation [2]. If the lightest supersymmetric particle is the tau-sneutrino, its decay may be realized only via R-parity violation (RPV): $\tilde{\nu} \rightarrow l^+l'^-$, $\tilde{\nu} \rightarrow q^+q'^-$.

If R – parity is violating, $e^-e^+ \rightarrow \tilde{\nu}\bar{\tilde{\nu}} \rightarrow \mu^+\mu^+e^-e^-$ process becomes very important. In this paper $\tilde{\nu}_\tau$ pair production at the CLIC with subsequent RPV decays into $e\mu$ pairs has been investigated. Feynman diagram for tau-sneutrino production process is shown in Figure 1.

The R-parity violation part of the MSSM superpotential is given by [2]

$$W_{RPV} = \frac{1}{2}\lambda_{ijk}L_iL_jE_k^c + \lambda'_{ijk}L_iQ_jD_k^c + \frac{1}{2}\lambda''_{ijk}U_i^cD_j^cD_k^c \quad (1)$$

where $L(E)$ is an $SU(2)$ doublet (singlet) lepton superfield and $Q(U, D)$ is (are) an $SU(2)$ doublet (singlet) quark superfield(s), and indices $i, j, k = 1, 2, 3$ denote flavour. The coefficients λ_{ijk} and λ''_{ijk} correspond to the lepton number violating and baryon number violating couplings, respectively.

RPV interaction Lagrangian responsible for $\tilde{\nu}_\tau \rightarrow \mu^+e^-$ and μ^-e^+ decays is given below:

Collider Parameters	$\sqrt{s} = 0.5$ TeV	$\sqrt{s} = 3$ TeV
$E(\sqrt{s})$, TeV	0.5	3
$L(10^{34} \text{ cm}^{-2} \text{ s}^{-1})$	2.3	5.9
$N(10^{10})$	0.68	0.372
$\sigma_x(\text{nm})$	202	45
$\sigma_y(\text{nm})$	2.3	1
$\sigma_z(\mu\text{m})$	44	44

Table I: Main parameters of CLIC. Here N is the number of particles in bunch. σ_x and σ_y are RMS beam sizes at Interaction Point (IP), σ_z is the RMS bunch length.

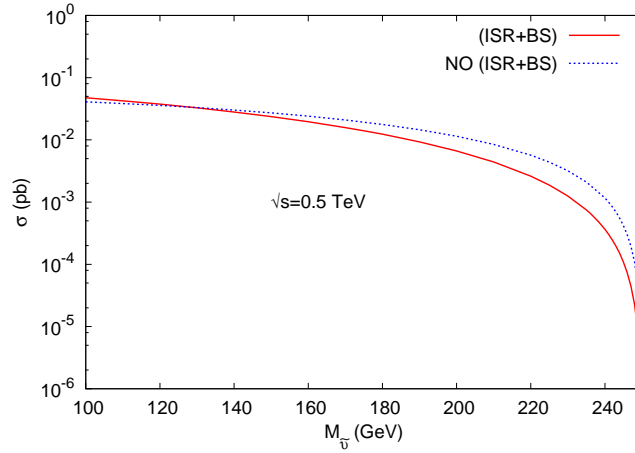


Figure 2: Cross sections for $e^-e^+ \rightarrow \tilde{\nu}\tilde{\nu}$ process at CLIC with $\sqrt{s} = 0.5$ TeV.

$$L = -\frac{1}{2}\lambda_{312}\tilde{\nu}_{\tau L}\bar{e}_R\mu_L - \frac{1}{2}\lambda_{321}\tilde{\nu}_{\tau L}\bar{\mu}_R e_L + h.c. \quad (2)$$

For the numerical calculations we implement the Lagrangian (2) into the CALCHEP MSSM package [3]. The cross-section for pair production of tau-sneutrinos at CLIC with $\sqrt{s} = 0.5$ TeV is shown Figure 2. Initial State Radiation (ISR) and Beamstrahlung effects at CLIC are calculated with CALCHEP program using beam parameters given in Table 1 [4, 5].

It is seen from Figure 2, that ISR and BS effects leads to increasing (decreasing) of the cross-section for $M_{\tilde{\nu}_\tau}$ below (above) 130 GeV. In Figure 3 we present similar calculations for the CLIC with $\sqrt{s} = 3$ TeV. It is seen that ISR and BS effects are more effective at higher

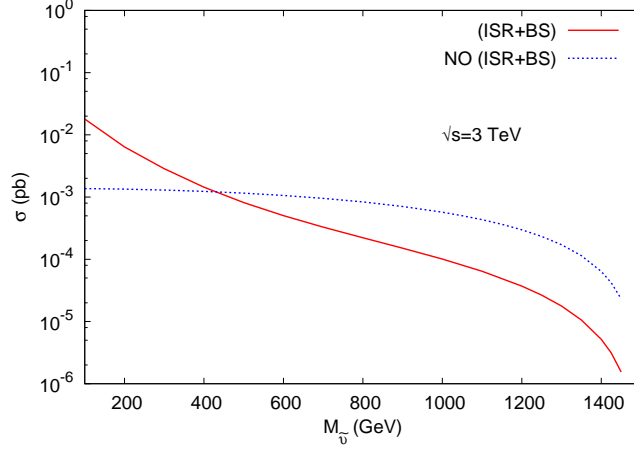


Figure 3: Cross sections for $e^-e^+ \rightarrow \tilde{\nu}\tilde{\nu}$ process at CLIC with $\sqrt{s} = 3$ TeV.

center of mass energy. ISR+BS effects lead to increasing of the cross sections for $M_{\tilde{\nu}_\tau} < 450$ GeV. After $M_{\tilde{\nu}_\tau} = 450$ GeV, ISR+BS effects decrease the cross sections.

We propose $e^-e^+ \rightarrow \tilde{\nu}_\tau\tilde{\nu}_\tau \rightarrow (\mu^+e^-)(\mu^+e^-)$ backgroundless process to analysis at CLIC. In order to analyze signal following basic cuts are applied: $P_T > 20$ GeV and $|\eta| < 2.5$ for the final state electrons and muons. Assuming $\lambda_{321} = \lambda_{312}$ and taking other possible RPV interaction constant to be 0, which means $Br(\tilde{\nu}_\tau \rightarrow \mu^+e^-) = Br(\tilde{\nu}_\tau \rightarrow \mu^+e^-) = 1/2$, we obtain cross section values given in Table 2 (3) for CLIC with $\sqrt{s} = 0.5$ TeV (3 TeV). Event number given in the last columns include both $\mu^+\mu^+e^-e^-$ and $\mu^-\mu^-e^+e^+$ final states.

In order to estimate statistical significance we have used following formula:

$$S = \frac{\sigma_s}{\sqrt{\sigma_s + \sigma_B}} \sqrt{L_{int}} \quad (3)$$

Here, S is statistical significance, σ_s is signal cross sections values, σ_B is background cross sections and L_{int} is integrated luminosity. We have backgroundless processes therefore σ_B is taken zero. From Eq. (3), discovery (5σ), observation (3σ) and exclusion (2σ) limits for tau-sneutrino at CLIC with $\sqrt{s} = 0.5$ TeV are obtained as follows: achievable tau-sneutrino mass values are 243 GeV for discovery, 248 GeV for observation and 251 GeV for exclusion. Corresponding values for CLIC with $\sqrt{s} = 3$ TeV are : 1030 GeV for discovery, 1225 GeV for observation and 1325 for exclusion.

So far the ideal case, namely, maximal possible Branching Ratio (Br) for the channel madden consideration had been analyzed. In more general case Branching Ratio is less than

$M_{\tilde{\nu}_\tau}$ (GeV)	Cross Section (pb)	Event Number (N)
100	8.00×10^{-3}	3686
120	7.02×10^{-3}	3230
140	5.80×10^{-3}	2676
160	4.25×10^{-3}	1957
180	2.70×10^{-3}	1269
200	1.51×10^{-3}	696
220	6.10×10^{-4}	279
240	9.60×10^{-5}	44
250	1.10×10^{-5}	5

Table II: Cross sections and event number depending on mass of tau-sneutrinos at $\sqrt{s} = 0.5$ TeV with $P_T > 20$ GeV and $|\eta| < 2.5$ cuts.

$M_{\tilde{\nu}_\tau}$ (GeV)	Cross Section (pb)	Event Number (N)
100	3.08×10^{-3}	3629
200	1.32×10^{-3}	1562
400	3.35×10^{-4}	395
600	1.21×10^{-4}	142
800	5.35×10^{-5}	63
1000	2.42×10^{-5}	28
1200	8.82×10^{-6}	10
1300	4.21×10^{-6}	5
1400	1.27×10^{-6}	2

Table III: The same as for Table 2 but for $\sqrt{s} = 3$ TeV.

1/2, because of other possible decay channels. In Figure 4 we present 5σ , 3σ and 2σ plots for $Br(\tilde{\nu}_\tau \rightarrow \mu^+ e^-) \times Br(\widetilde{\nu}_\tau \rightarrow \mu^+ e^-)$ depending on the $\tilde{\nu}_\tau$ mass for CLIC with $\sqrt{s} = 0.5$ TeV. One can see from Figure 4 that for $Br(\tilde{\nu}_\tau \rightarrow \mu^+ e^-) = Br(\widetilde{\nu}_\tau \rightarrow \mu^+ e^-) = 1/20$ (40 times smaller than ideal case) 5σ , 3σ and 2σ limits become 150 GeV, 190 GeV and 215 GeV, respectively. Corresponding plot for $\sqrt{s} = 3$ TeV are presented in Figure 5.

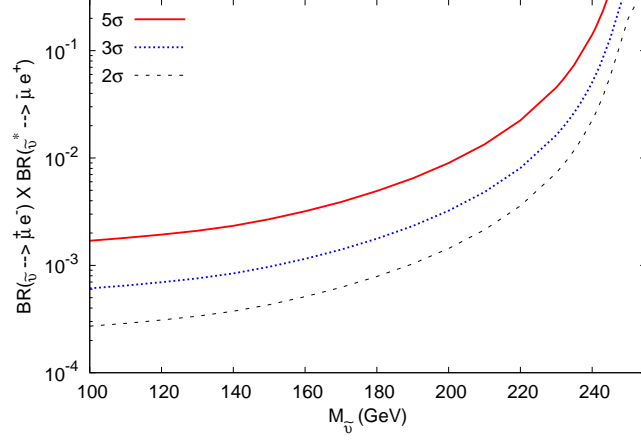


Figure 4: Achievable limits for $Br(\tilde{\nu}_\tau \rightarrow \mu^+ e^-) \times Br(\tilde{\nu}_\tau \rightarrow \mu^+ e^-)$ versus tau-sneutrino mass values at CLIC with $\sqrt{s} = 0.5$ TeV.

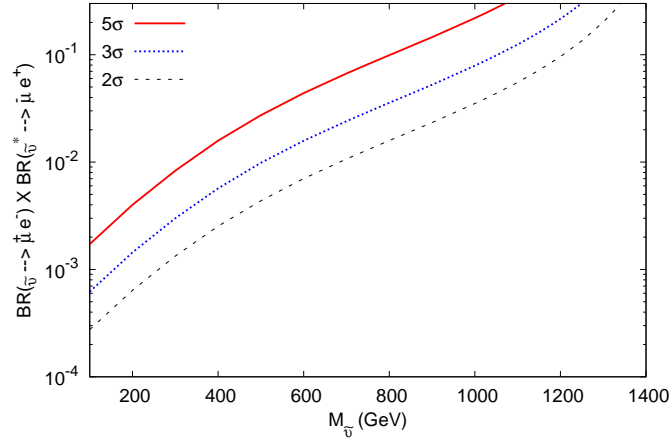


Figure 5: Achievable limits for $Br(\tilde{\nu}_\tau \rightarrow \mu^+ e^-) \times Br(\tilde{\nu}_\tau \rightarrow \mu^+ e^-)$ versus tau-sneutrino mass values at CLIC with $\sqrt{s} = 3$ TeV.

In the Table 4 (5) discovery, observation and exclusion limits for $Br(\tilde{\nu}_\tau \rightarrow \mu^+ e^-) \times Br(\tilde{\nu}_\tau \rightarrow \mu^+ e^-)$ at the CLIC with $\sqrt{s} = 0.5$ TeV (3 TeV) are given for several values of the $\tilde{\nu}_\tau$ mass.

In conclusion, the process $e^+ e^- \rightarrow \tilde{\nu}_\tau \tilde{\nu}_\tau \rightarrow \mu^+ \mu^+ e^- e^- (\mu^- \mu^- e^+ e^+)$ will provide powerful signature for LSP $\tilde{\nu}_\tau$, if $Br(\tilde{\nu}_\tau \rightarrow \mu^+ e^-)$ and $Br(\tilde{\nu}_\tau \rightarrow \mu^+ e^-)$ are sufficiently large.

[1] H. E. Haber and G. L. Kane, Phys. Rep. 117, 75 (1985).

$M_{\tilde{\nu}_\tau}$, GeV	5σ	3σ	2σ
120	0.00193	0.00069	0.00031
160	0.00319	0.00115	0.00051
200	0.00898	0.00323	0.00144
240	0.14066	0.05064	0.02251

Table IV: Achievable limits of $Br(\tilde{\nu}_\tau \rightarrow \mu^+ e^-) \times Br(\tilde{\nu}_\tau \rightarrow \mu^+ e^-)$ at the CLIC with $\sqrt{s} = 0.5$ TeV.

$M_{\tilde{\nu}_\tau}$, GeV	5σ	3σ	2σ
100	0.00172	0.00062	0.00027
400	0.01582	0.00569	0.00253
800	0.09899	0.03564	0.01584
1100	0.34578	0.12448	0.05532

Table V: Achievable limits of $Br(\tilde{\nu}_\tau \rightarrow \mu^+ e^-) \times Br(\tilde{\nu}_\tau \rightarrow \mu^+ e^-)$ at the CLIC with $\sqrt{s} = 3$ TeV.

- [2] R. Barbier *et al.*, Phys. Rep. 420, 1 (2005).
- [3] A. Pukhov *et al.*, e-print hep-ph/9908288 (1999); e-print hep-ph/0412191 (2004).
- [4] H. Braun, *et al.*, CLIC 2008 parameters, CERN report No: CERN-OPEN-2008-21, CLIC-NOTE-764, Geneva (2008).
- [5] <http://clic-meeting.web.cern.ch/clic-meeting/clictable2010.html>, CLIC PARAMETER LIST 3 TeV.